THE CIRCULATION AT THE 10-MILLIBAR CONSTANT PRESSURE SURFACE OVER NORTH AMERICA AND ADJACENT OCEAN AREAS

July 1957 through June 1958

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ABSTRACT

A recently published set of 10-mb. charts analyzed three times monthly, July 1957 through June 1958, is used as a basis for discussion of the high stratospheric circulation during those first 12 months of the International Geophysical Year. There is a slow, steady transition from summer easterlies to winter westerlies which appear first in high latitudes and then strengthen and expand southward. In January and February 1958, the circulation breaks down rapidly and in a highly complex manner. By May, polar easterlies become established and spread southward to merge with the intensifying subtropical easterlies.

Several related topics on the nature of medium- and large-scale developments are discussed.

1. INTRODUCTION

Recent advances in science and technology have generated a requirement for a more detailed knowledge of atmospheric circulation at increasingly high levels. Rockets and missiles regularly penetrate the 10-mb. surface (near the 31-km. level). Unmanned balloons carrying a variety of instrumentation have drifted for days near the 30-km. level, and one such balloon is known to have attained a height exceeding 45 km. At least three men have already journeyed as high as the 10-mb. surface. The late Capt. Iven C. Kincheloe reached 38 km. in a U.S. Air Force X–2 rocket aircraft on September 7, 1956; Maj. David G. Simons ascended to 31 km. in a sealed gondola carried by a 6,000,000 cu. ft. plastic balloon on August 20–21, 1957; and Capt. Joe B. Jordan flew an F–104C jet plane to 31.5 km. on December 14, 1959.

The tremendous eruption of the Krakatoa volcano on August 27, 1883 (Wexler [20]), threw material from the surface of the earth to a height of 32 km. where the dust cloud circled the earth at an average speed of 63 kt. to give evidence of equatorial easterlies at this level. More recently, debris has been cast up to the 30-km. level by hydrogen-bomb explosions. There, depending upon season and latitude, it has been carried eastward or westward around the earth in a few days. Some of this material has even drifted across the equator to fall out in the Southern Hemisphere.

What do we have in the way of reliable meteorological information about the middle layers of the stratosphere? Can ascent to these heights be made with reasonable confidence in the sort of weather and winds that may be encountered there? Prior to the International Geophysical Year these heights were frequently attained by ascents made at a score of United States military radiosonde stations scattered about the Northern Hemisphere. In addition, occasional special meteorological probes were made to 30 km. or higher. The data from such ascents were adequate for an estimate of the generalized temperature and wind distribution at 10 mb. but left unresolved many questions regarding such details as the amplitude, wavelength, and speed of perturbations at this level. Other topics requiring more accurate data for greater understanding are related to the vertical structure, development, and maximum strength of the wintertime Arctic stratospheric jet stream (or "Astrajet" as we shall call it here) and to the phase relationships between streamlines and isotherms during progression, retrogression, and rapid development of disturbances in the circulation of the stratosphere.

With the beginning of the International Geophysical Year, sufficient effort was placed on the attainment of great heights by routine radiosonde runs for depiction of the daily circulation at 10 mb. with reasonable accuracy over a large area. Recently, increasing numbers of observational studies (see references in this paper and in Hare [2]) have shown, in various degrees of detail, some characteristics of the circulation and climatology of the stratosphere. The Stratospheric Analysis Project of the U.S. Weather Bureau has already published [18] a set of 10-mb. charts, analyzed three times monthly for the first 12 months of IGY, July 1957 through June 1958. Analysis of additional sets of 10-mb. charts and of 30-mb.

(24 km.) charts for the same period is now in process. Another important function of this project is the analysis of daily 100-mb. (16.5 km.) and 50-mb. (20 km.) Northern Hemisphere charts for the IGY period, July 1957 through December 1958 [19].

The purpose of this paper is to describe the major features of the 10-mb. circulation and its changes in the period July 1957 through June 1958. The description is based primarily on the published set of 10-mb. charts [18] and selected charts from this set are shown in figures 2, 4–7, and 10–12.

2. PROBLEMS OF PROCESSING AND ANALYZING 10-MB. DATA

Even at best, observed 10-mb. data are scarce and extrapolated data must be depended upon as a supplement. The modest budget of the project did not permit an elaborate system of building up the 10-mb. analysis from lower levels on a routine basis by use of mean virtual temperature charts and differential analysis. Instead, individual soundings that reached nearly to the 10-mb. surface were extrapolated. In other cases, soundings were reconstructed from time-section data coupled with data from surrounding stations.

Random errors in temperature and height data are far larger at 10 mb. than at lower levels and, moreover, are superimposed upon a large systematic diurnal variation. Much of the diurnal variation is spurious, being caused by alternate solar heating and nocturnal cooling of the temperature element of the radiosonde. A great amount of instrument research will have to be performed before the exact nature of the radiation error is known for all types of radiosondes, but to reduce the difficulty of stratospheric analysis it is sufficient to use the method of Teweles and Finger [15]. This system eliminates the diurnal variation of most types of United States radiosondes used during the IGY by reducing daytime values to the level of nighttime values. The magnitudes of the temperature and height corrections applied to the 10-mb. data are shown in figure 1. The corrections shown for the duct-type instruments are in addition to corrections [17] already applied during evaluation of the raw data at the radiosonde station.

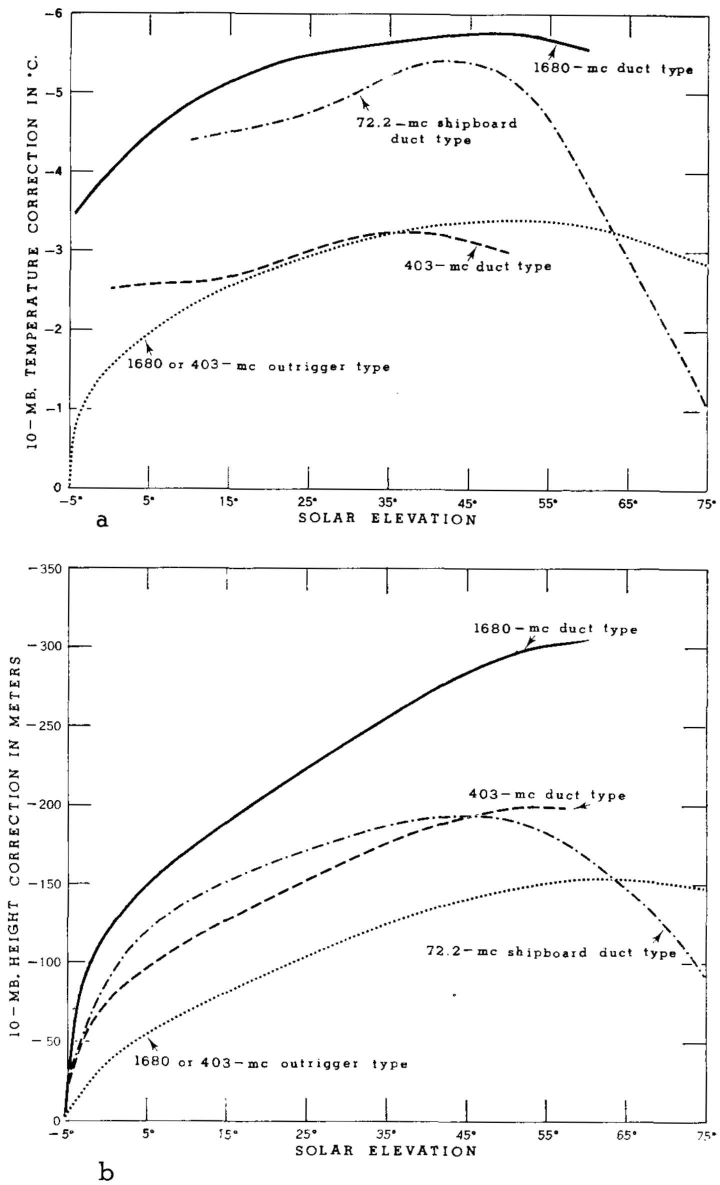

Figure 1.—Temperature (a) and height (b) corrections for use with 10-mb. data reported from the principal United States radiosondes used during the International Geophysical Year.

Radiation theory indicates that heat losses by some types of thermistors in darkness may cause reported nighttime 10-mb. temperatures to be as much as 2° C. below the true values. If this is true and there is no compensation by other effects such as stray battery heat, then the 10-mb. isotherms drawn on these charts should be labeled higher by that amount. There is evidence (Teweles and Finger [15]) that this temperature error, if it exists, does not differ much for various types of instruments and so would result in a fairly constant height error, having little effect upon the gradient of contour height. In determining the contour analysis, the wind data were found to be far more useful than the height data which, in fact, found their main use in the estimation of the values to be used in labeling the contours. Height data also had some use in the determination of the spacing of contours across large ocean or land areas having little or no wind data.

The sparsity of 10-mb. data made it necessary to utilize for the analysis not only the synoptic reports but also all other observations reaching to or nearly to the 10-mb. surface on the same day, the preceding day, or the following day. Comparison of the various reports entered at a station made it possible to discard obviously erroneous values and to interpolate between reports in order to find the most probable data at map time. In drawing contours to agree closely with the observed wind field, the analyst can give little weight to the reported

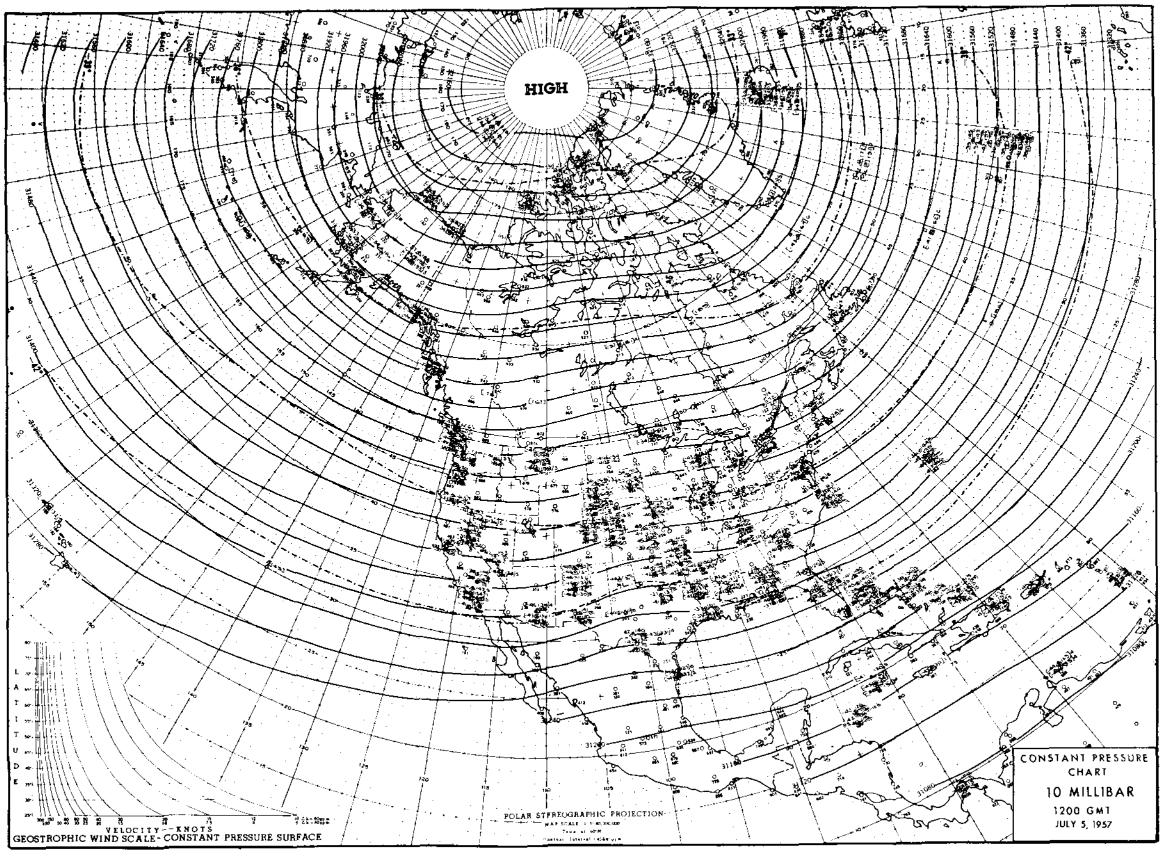

Figure 2.—The 10-mb. chart for 1200 GMT July 5, 1957, from [18]. Contours at intervals of 40m., isotherms (dot-dash lines) at intervals of 3° C.

heights. Furthermore, the analyst has little in the way of synoptic models for guidance with respect to probable contour and isotherm patterns or the phase relationship between them. Thus, the amount of subjectivity in the 10-mb. analysis is much greater than that found in the analysis of tropospheric charts. In spite of these factors, surprisingly little modification of the principal features of the circulation and temperature distribution shown in the final analyses is possible without disregarding more data than are better satisfied by the change.

Large-scale patterns with wavelength of the order of 6,000 km. are quite accurately shown by these analyses, and some medium-scale features have been revealed by conscientious efforts to detect and delineate them. Frequently, however, when their amplitudes are small these medium-scale perturbations tend to be obscured by the large observational errors. Nevertheless these 10-mb. charts serve a useful purpose by portraying important features of large-scale circulation changes for comparison with analogous changes at lower levels. Moreover, with these charts to act as a foundation, activity at still higher levels can be estimated, particularly if supplemental data from a few high-reaching balloon or rocket soundings are available.

3. THE SUMMER EASTERLIES

(July 1957 and June 1958)

Because the reference series of maps begins with the month of July, it is necessary here to discuss the summer easterlies by combining charts for two different summers. The 10-mb. chart for July 5, 1957 (fig. 2),* shows the typical summertime contour pattern with a High centered near the pole and circumpolar easterlies at all latitudes. This circulation persisted only until the beginning of August 1957, but in the following year became reestablished by the middle of June. The summertime circulation, once established, changes very little from day to day, at least in the large-scale pattern. Careful examination of wind directions during this period suggests the existence of small amplitude perturbations in the easterlies, but in the subtropics and lower mid-latitudes, the wind directions in these perturbations deviate little more than 10 degrees on either side of straight easterly.

An interesting feature of this summertime circulation

*Figures 2, 4, 5, 6, 7, 10, 11, and 12 are reproduced, after reduction to approximately one-half size, from the U.S. Weather Bureau [18] publication, *10-millibar Synoptic Weather Maps*. In the process, the plotted data have become illegible. Institutions or research groups having need for greater detail than is found here will be furnished with a copy of the booklet, as long as the supply lasts, upon request to Chief, U.S. Weather Bureau Reference R-3.42, Washington 25, D.C.

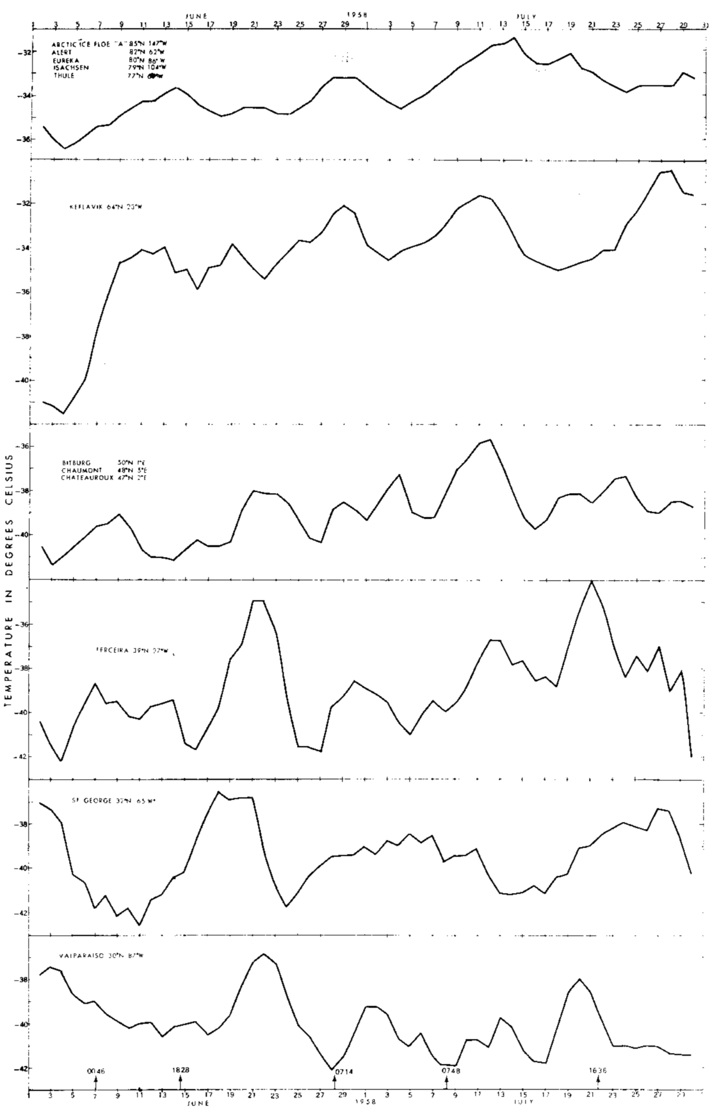

FIGURE 3.—10-mb. temperatures (3-day running means) at several stations from June–July 1958. A few individual values were extrapolated from as low as the 13-mb. level. Temperatures were adjusted to eliminate bias from radiational errors.

is the almost uniform contour gradient from the Arctic to the subtropics. This phenomenon seems to have only the trivial significance that the wind speed is inversely proportional to the sine of the latitude. The observed decrease of wind with latitude suggests solid rotation, but this would require the wind speed to vary with the cosine of the latitude with the greatest horizontal wind shear in the high latitudes instead of the lower mid-latitudes as observed.

The isotherm patterns suggest that, due to the influence of 24-hour radiation from the sun, the Arctic warms more rapidly than the areas south of the Arctic Circle. The areas of residual coolness in middle latitudes melt away during the month of June and appear to be absent by mid-summer when the isotherm pattern becomes nearly circumpolar without isolated closed centers.

Details of the early summer isotherm patterns are obscured by the large temperature errors charcteristic of 10-mb. data. These errors are frequently as large as the day-to-day temperature changes and in summer are equal to the horizontal temperature difference across a very wide area. The isotherm pattern may be overly smoothed since the analyst did not have the means to make a detailed analysis of the temperature variation at individual stations and thus may occasionally have disregarded an unusual but correct value.

Determining the reality of small temperature changes reported at 10 mb. is a difficult problem for the analyst. The magnitude of the changes he must recognize is indicated in figure 3 by 3-day running means of 10-mb. temperatures in areas where there are several nearby stations, or at stations where observations are taken four times daily. The period of the changes is roughly 10 to 15 days. Their magnitude increases from about 4° C. in the Arctic to 7° C. in middle latitudes, but seems to decrease again at lower latitudes. Of course, the real changes are somewhat larger than those of the 3-day running means and, in addition, random errors have been greatly reduced by this averaging process. The curves of figure 3 show minor 10-mb. temperature variations ranging from 2° or 3° C. near the pole to 5° or 6° C. at 30° N. Since the atmosphere at 10 mb. in summer is statically quite stable, vertical motion of only one-half kilometer would produce sufficient adiabatic heating or cooling to explain these observed temperature changes of only 5° or 6° C.

Scherhag [11] has already discussed the Berlin 20-mb. and Bitburg 25-mb. temperature changes over Germany during this period (June–July 1958). Random errors in the data were subdued by preparing 5-day running means of observed temperatures. He remarks that a solar eruption occurred at 0400 GMT, July 7 and after the interval required for solar particles to reach the earth from such a disturbance, an extraordinarily strong terrestrial magnetic and ionospheric storm was observed on July 8. According to Scherhag, such temporal relationships between solar eruptions, magnetic and ionospheric storms, and sudden warmings of the stratosphere are not accidental.

The temperature changes shown in Scherhag's paper are comparable in size with those in the 10-mb. temperatures shown here (fig. 3). The temperature rise, following the sudden commencement of the ionospheric disturbance at 0748 GMT July 8 can be observed not only in western Europe but also over the Atlantic Ocean at Terceira and Keflavik and less markedly over the Arctic. St. George and Valparaiso temperatures at this time show no definite response. Over these latter stations and at Terceira more pronounced and relatively simultaneous temperature peaks occurred from June 18 to 22. Other sudden commencement dates given in an article by Williams [23] are indicated in figure 3 but heralded much weaker ionospheric disturbances (U.S. National Bureau of Standards [16]) than that of July 8. For this reason and because it occurred so early, the sudden commencement of June 14

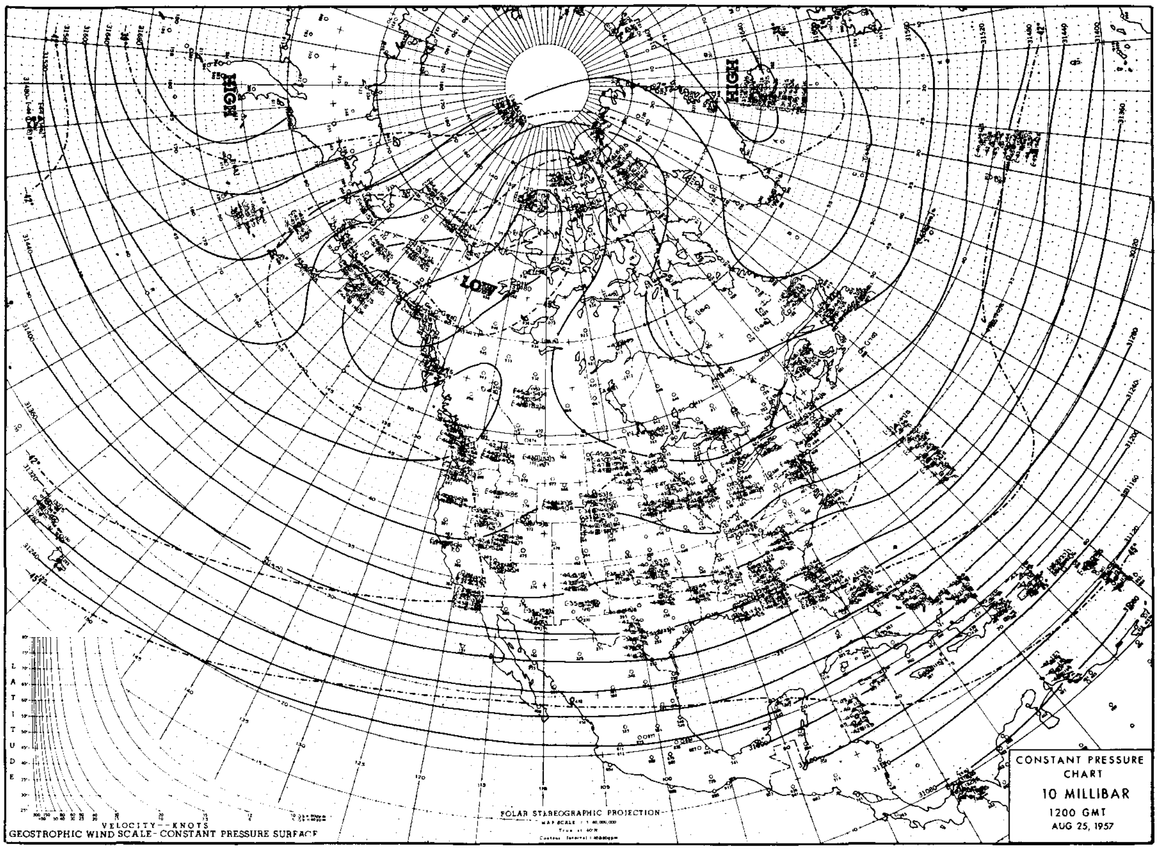

Figure 4.—The 10-mb. chart for 1200 GMT August 25, 1957 (from [18]. Contours and isotherms as in figure 2.

hardly seems capable of explaining the June 18 to 22 warmings. A careful investigation of the changes of 10-mb. circulation associated with these changes of 10-mb. temperature is highly desirable but requires painstaking study beyond the scope of this paper.

4. TERMINATION OF THE REIGN OF THE EASTERLIES

(August and September 1957)

In the first half of August 1957, the high-latitude easterlies at 10 mb. began to buckle and slowly break over into westerlies. By August 25 (fig. 4), a closed circulation had developed over the Yukon Valley. North of the 45th parallel only very weak easterlies remained and meridional flow was as prevalent as zonal flow. Within the next 10 days a radical change in the position of the lowest pressure took place. Although a trough remained in western Canada, a change to northerly winds at Thule in northwestern Greenland shows that the heights had dropped more rapidly to the east of Greenland than over the North American Arctic. The general decrease in height of the pressure surface is a logical manifestation of the shrinkage of the polar atmosphere as a result of seasonal cooling. However, part of the decrease was accompanied by westward movements of the low center since the wind at Thule switched to southerly by mid-September. By the end of September the deepening trough had taken a central position in Canada and extended its influence southward to the Western Plains of the United States.

The ridge separating the still strong subtropical easterlies from the expanding ring of polar westerlies was first well-marked in early September along the 45th parallel. By late September, the ridge had migrated a full 10° of latitude southward, and the speed of the subtropical easterlies had generally fallen below 50 kt. Meanwhile the temperature at the pole fell some 20° C. from its summertime peak.

At 10 mb. in high latitudes during September and October the atmosphere cools at the rate of about 15° C. a month, suggesting a strong tendency toward radiative equilibrium. The parallelism of contours and isotherms is a generally reliable indication that there is little or no vertical transport of heat at this time. There may still be sinking motion to compensate for the cooling and shrinking of the polar layers. Furthermore, the gradual acceleration of the zonal flow requires an inflow across contours toward the pole. This inflow must be more than compensated by outflow at another level to permit the continued lowering of the pressure surfaces. Sinking of the air with outflow at lower levels provides the most logical explanation. Radiational cooling must then be called upon both to compensate for the adiabatic heating and to explain the decrease in temperature.

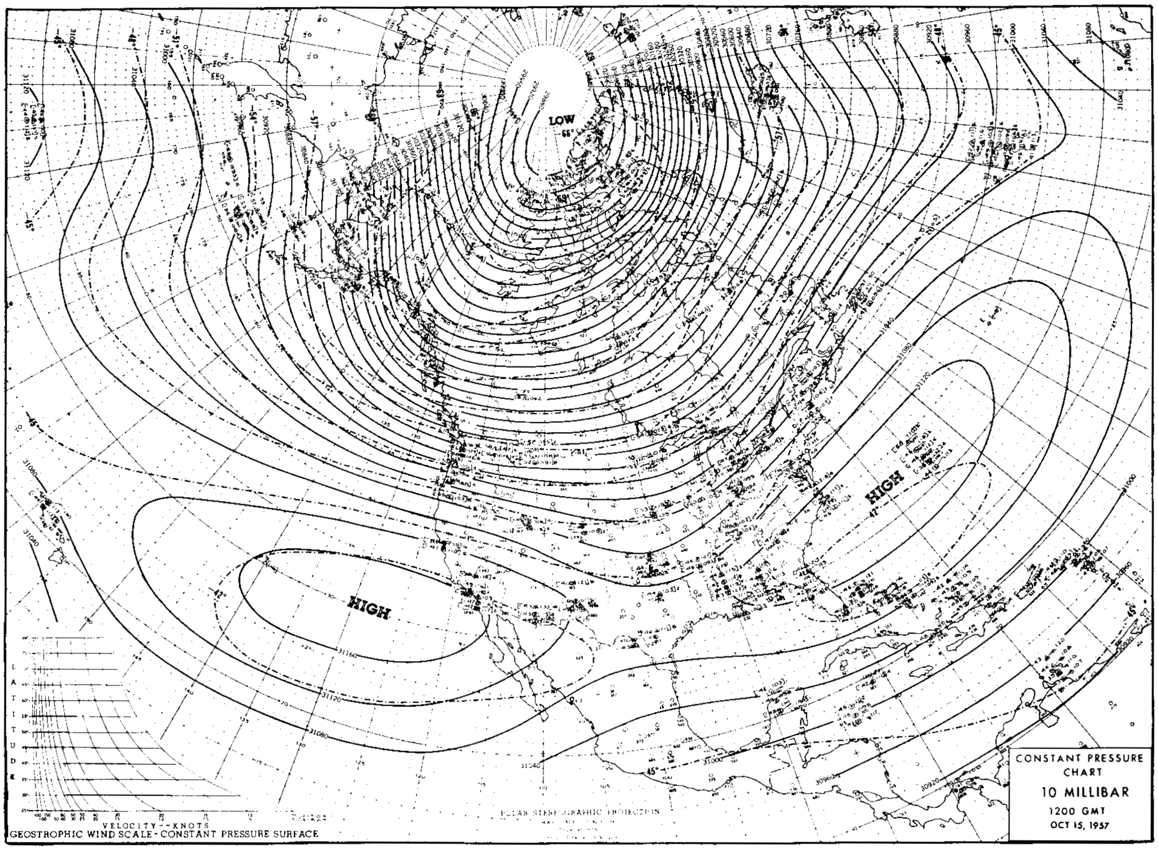

Figure 5.—The 10-mb. chart for 1200 GMT October 15, 1957, from [18]. Contours and isotherms as in figure 2.

5. THE INCREASING WESTERLIES

(October to mid-November 1957)

During October 1957, the cooling and lowering of stratospheric pressure surfaces and increase of westerly wind speeds in the high latitudes continued at an accelerated pace. As the polar temperature dropped 18° C. from September 25 to October 25, the 10-mb. surface at the pole sank one full kilometer just as it did during the previous month. In just 10 days preceding October 15 (fig. 5) temperatures over the Yukon basin dropped 8° C. or more with corresponding height falls of more than one-half kilometer. During the next 10 days, the trough line moved eastward to a position over Greenland where heights fell 700 meters and temperatures 12° C. in 10 days. These latter decreases seem to involve dynamic as well as radiational cooling.

The westerly circulation during the period from early October to early November came as close to being circumpolar as at any other time during the 1957–58 cold season. Even so there was a notable tendency in the autumn toward eccentricity of the pattern with the principal low center displaced toward the European side of the pole. This eccentricity is closely associated with the persistent tendency toward anticyclogenesis in the stratosphere over the Aleutian area.

One theory for explaining the existence of this climatological feature is that the center of the circulation is displaced from the North Pole due to enhanced radiative heat losses over the "cold poles" of Greenland and northern Siberia. By the same logic, the center is thrust away from the Aleutian area where the ocean surface is abnormally warm for that latitude. This explanation is discounted by Wexler and Moreland [22]. Its weakness is that small differences in long-wave radiation could not hold isotherms stationary in the face of advective temperature effects that often are larger by two orders of magnitude.

Another explanation, given in an earlier paper (Teweles [13]) places the energy source in the tropospheric jet stream that normally passes over Japan in winter, then spreads out, and weakens over the Pacific. This feature is strikingly illustrated by charts of the mean 300-mb. wind, temperature, and kinetic energy distribution over the Northern Hemisphere produced by Lahey et al. [3]. These charts show that between October and November and again between November and December there are marked increases in the mean strength of the jet stream over Japan. This portion of the jet stream remains at peak strength through February. Although the weaker jet stream of September and October loses little of its speed while crossing the Pacific, the jet stream during the months when its kinetic energy over Japan is greatest loses from one-half to three-quarters of its energy by the time it crosses the North American coastline. In the region surrounding the decelerating current, the conversion of kinetic energy into potential energy requires an

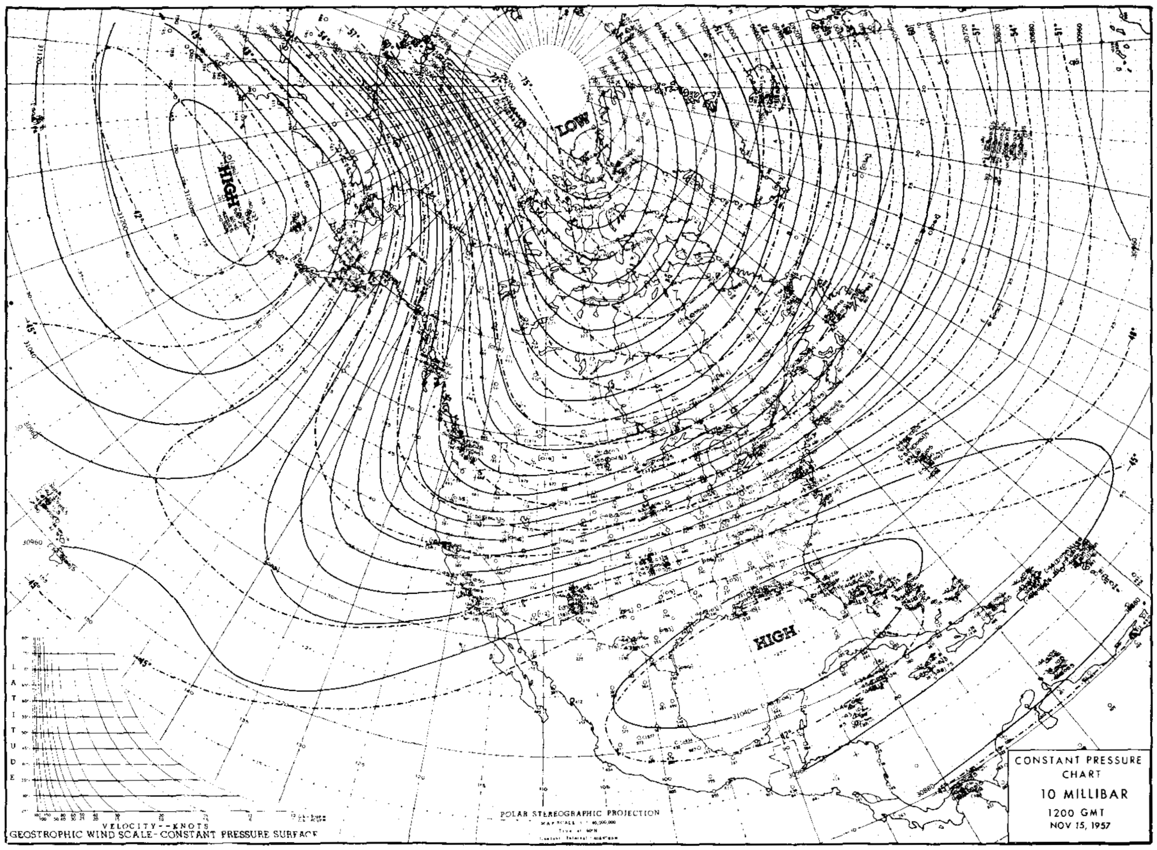

Figure 6.—The 10-mb. chart for 1200 GMT November 15, 1957, from [18]. Contour interval 80 m.; isotherm interval 3° C.

arrangement of vertical motions over the Pacific that is to be expected around an exit zone as discussed by Scherhag [10]. This explanation requires that the decelerating tropospheric westerly jet stream, bearing to the right or southward toward high pressure, will tend over most of the cold season to evacuate the layers near the tropopause level over the Aleutians. The net sinking motion above that level will produce stratospheric temperatures high for that latitude. Convergence and inflow at the high levels will maintain a strongly baroclinic region by packing isotherms between this warm air and the body of cold air produced within the Arctic Circle. The Astrajet must intensify with height to extremely high velocities in obedience with the thermal wind equation. High pressure is built up in the warm Aleutian stratosphere to produce the necessary balancing pressure gradient. This current then carves out a path of constant absolute vorticity for itself southeastward across Canada. In this explanation, the proposed cause, the tropospheric jet stream, transports sufficient energy to explain the vertical motions necessary to hold the existing field of stratospheric isotherms stationary in the face of the strong advective tendency. The generation of an indirect circulation in the region downstream from a jet stream wind maximum is discussed in greater detail by Riehl and Teweles [8].

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6. A PULSATION OF THE ALEUTIAN HIGH

(Mid-November 1957 to early January 1958)

On November 15 (fig. 6) the most noteworthy feature of the 10-mb. chart was the extensive anticyclone centered over the Aleutian Islands. This warm anticyclone had built up quite rapidly and was influencing the circulation over the entire North Pacific Ocean. The 10-mb. temperatures over the Aleutians were 25° C. or more warmer than at the same latitude over the interior of Canada. Computed heights and extrapolated winds give evidence of 150-kt. speeds in the wind current which curved clockwise from northeastern Siberia across the Arctic Ocean and Alaska into the Gulf of Alaska.

With the buildup of the anticyclone over the Aleutians there was extensive segmentation of the subtropical high pressure belt that prior to October 15 (fig. 5) and until early November was fairly continuous along 30° N. latitude. This belt as long as it remained continuous tended to isolate the subtropical easterlies from the mid-latitude westerlies. After the break up, as indicated in figure 6 by the circulation in the vicinity of both Hawaii and Mexico, large amounts of air from the deep Tropics were able to penetrate northward and mix with the polar currents. This may be a general feature of the circulation for it was at just this time of the year 1883 that the first

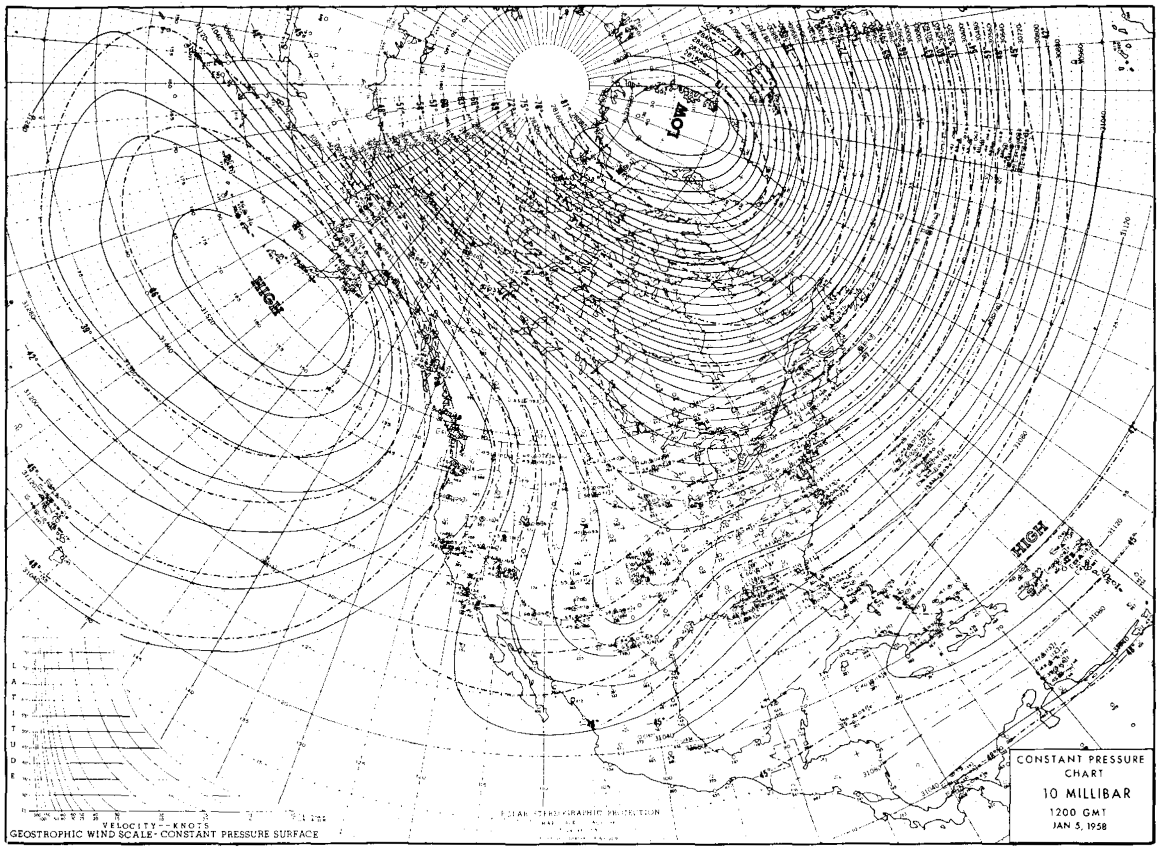

FIGURE 7.—The 10-mb. chart for 1200 GMT January 5, 1958, from [18]. Contour interval 80 m.; isotherm interval 3° C.

evidence of the Krakatoa dust cloud was reported in mid-latitudes (Wexler [20]). The cloud had slowly worked its way northward during September and October from its origin at 6° S., 105° E. We may presume that in 1883 as in 1957 the high pressure belt was slowly pressed southward toward the subtropics. As the two phenomena crossed, the dust cloud was carried away in the westerlies.

By late November 1957, the highest portion of the 10-mb. surface had retrogressed southwestward to a position just east of Japan. Along with the decrease in height of the 10-mb. surface over Alaska, temperatures plunged as much as 20° C. This cooling of the western portion of a trough during the retrogression of stratospheric systems was also noted as a feature of the circulation breakdown of January–February 1957 (Teweles [13]).

The westerly circulation in high latitudes by late November had again become nearly circumpolar with the lowest portion of the 10-mb. surface close to the North Pole. Flat waves, two or three in number, apparently existed in this circulation for, in addition to the Pacific ridge, another is delineated near the British Isles by southerly wind components over the Atlantic and northerly components over western Europe.

During most of December there were no major changes in the pattern, except for a slight filling of the polar low center and an irregular eastward movement of the 10-mb. systems. A remarkable change took place about the beginning of the new year, for on January 5, 1958 (fig. 7), a great ridge again occupied the stratosphere over the Aleutians. In its broad features, the circulation closely resembles that for November 15 (fig. 6). Several important differences should be noted, for they may be significant in determining the far different sequence of events that follows these situations. On November 15 (fig. 6), the height difference between Aleutian High and Arctic Low was a little more than 2 km., but on January 5, the difference was more than 3½ km. Consequently the wind current between centers was much stronger and the area of strong winds extended farther downstream on the latter date. Over the northern Atlantic, reported wind speeds doubled to more than 100 kt. between the two dates. Over Alaska and Canada, low temperatures, high winds, and scarcity of special high-flight balloons combined to prevent wind observations to great heights. However, the contour gradient requires geostrophic winds of 200 kt. over Alaska and 100 to 200 kt. southeastward across Canada.

The isotherm-contour relationship over Alaska and western Canada also differs markedly on these charts. There was little cross-isotherm flow on November 15, but on January 5 horizontal thermal advection of as much as 3° C./hr. was indicated. Since there can be little movement of isotherms in the face of 100- to 200-kt. winds this condition in combination with nearly isothermal lapse rates and adiabatic flow requires upward vertical motion of 3 to 5 cm./sec. over a distance of more than 2,500 km.

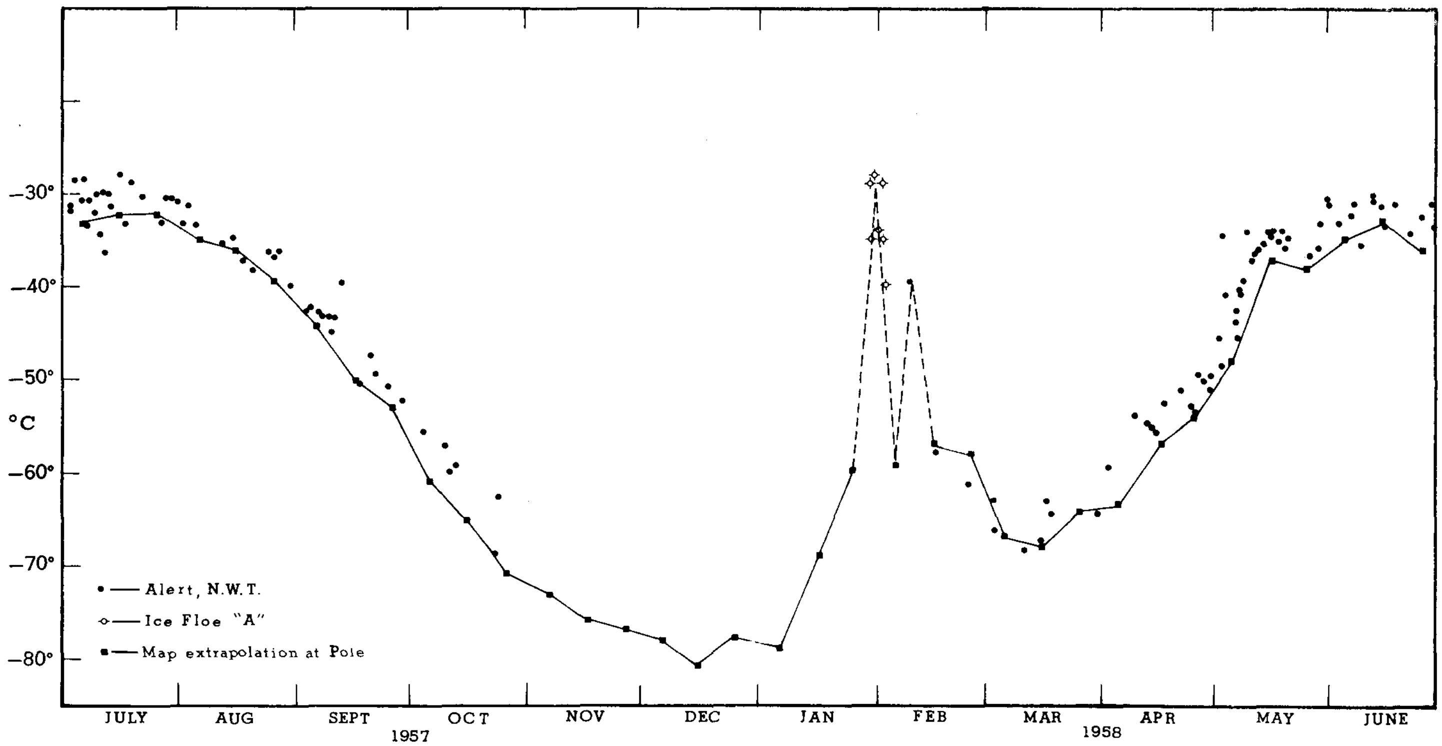

FIGURE 8.—The curve of 10-mb. temperatures extrapolated at the North Pole on each chart of [18]. All 10-mb. temperatures reported during the 12 months from Alert N.W.T. (82° N., 62°20′ W.) are included, supplemented by 10-mb. temperatures reported during January and February 1958 from Ice Floe Station "A". Daytime station temperatures are plotted from the records without reduction to nighttime values, while values extrapolated from the 10-mb. charts depend on the isotherm analysis which includes the reduction.

7. THE PERIOD OF "EXPLOSIVE WARMING"

(Mid-January to early February 1958)

In the first half of January 1958, the wavelength of the 10-mb. flow shortened as a consequence of anticyclogenesis in the Azores area while the Aleutian anticyclone held fast. Thereafter the stratospheric circulation of the Northern Hemisphere underwent a series of radical and relatively rapid changes. Some aspects of these changes observed in early 1958 have already been described in more detail elsewhere (Hare [2], Palmer [6], and Scherhag [12]). A previously published series of 25-mb. charts for January 17, 24, 28, and 29, and February 1 and 4, 1958 (Teweles and Finger [14]) shows that after January 24 the Aleutian high pressure center moved northwestward, recurved near the pole and then moved back toward its original position. Looking only at the January 24 and February 4 25-mb. charts (or the January 25 and February 5 10-mb. charts (U.S. Weather Bureau [18])), one would erroneously conclude that the anticyclone in that period had merely moved eastward a short distance. Thus, while a 10-day interval between 10-mb. charts is, during much of the year, adequate for most purposes, there are times when a daily series of charts is needed to detail sweeping changes of the 10-mb. surface as rapid as those of the troposphere.

The effect of the warming on the annual march of temperature in the polar region is vividly shown in figure 8 by temperatures observed at Alert and Ice Floe Station "A" superimposed on a graph of North Pole temperatures estimated from the entire set of 10-mb. charts (see fig. 15 of Wexler [21] for temperatures at lower levels). In the darkness of the polar night, high 10-mb. temperatures of −28° C. at 1200 GMT on January 30, 1958, and −29° C. at 1200 GMT on February 1 were reported over Ice Floe Station "A". A sharp drop in 10-mb. temperature thereafter is indicated by the 25° C. decrease in reported 20-mb. temperatures to −61° C. at 0000 GMT on February 4. A second warming occurred with a peak of about −40° C. at 10 mb. on February 10 and was itself followed by rapid cooling. Although cooling followed both warmings, the temperature did not closely approach the seasonal low of nearly −80° C. which was recorded on January 5. The 10-day cycle in the 20-mb. temperatures also appeared at Keflavik, Iceland (table 1), during this same period. The temperature changes at Keflavik were no less pronounced than those at the pole. Like those at the pole the Keflavik temperatures on map days were all very low, and the warmings could be missed by an inspection of just the published 10-mb. charts.

On February 1 (fig. 9), the high center at 10 mb. was

TABLE 1.—*20-mb. temperatures at Keflavik, Iceland, Jan. 25–Feb. 15, 1958*

Jan. 25	Jan. 30	Feb. 5	Feb. 10	Feb. 15
0000 GMT	1800 GMT	0000 GMT	0000 GMT	0600 GMT
−71° C.	−14° C.	−71° C.	−26° C.	−61° C.

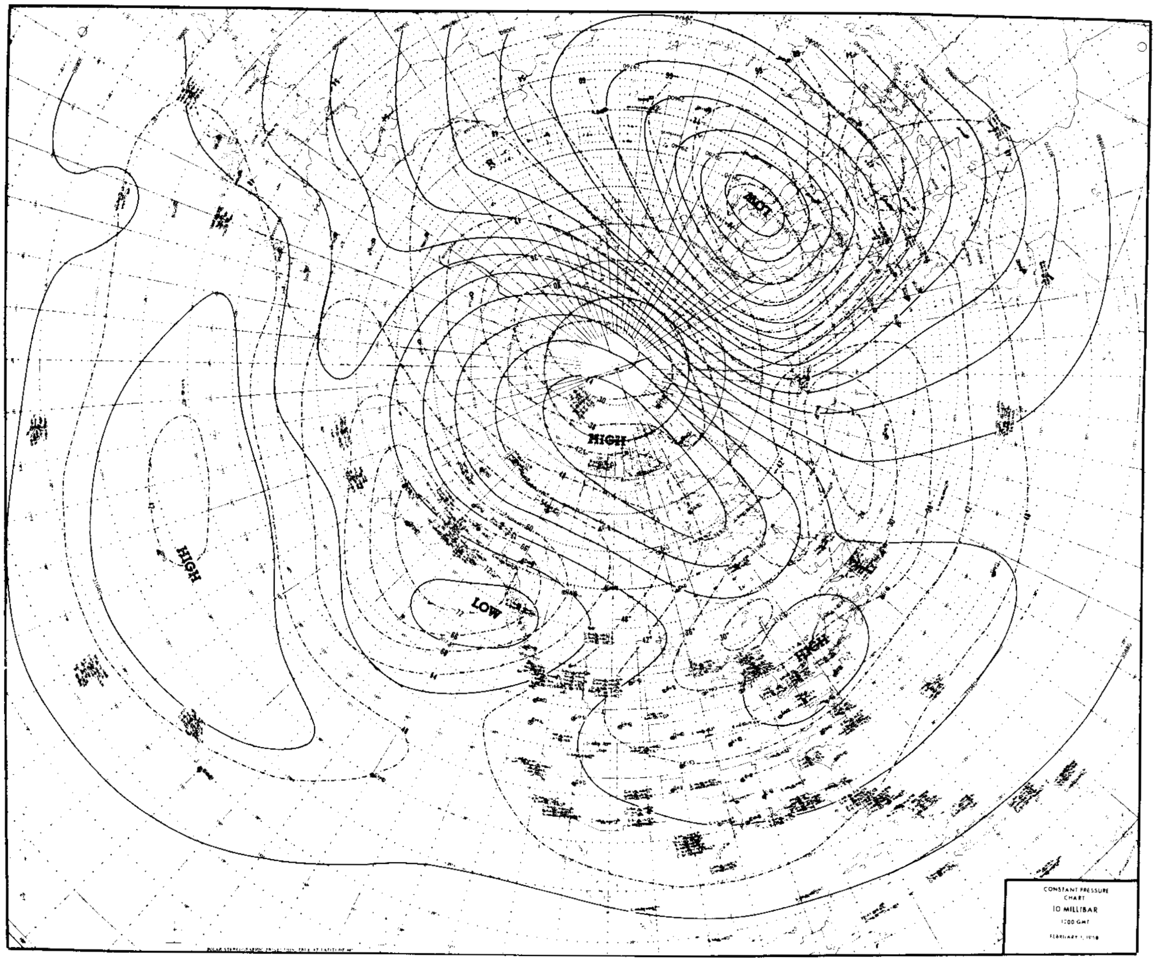

Figure 9.—The 10-mb. chart for 1200 GMT February 1, 1958. Contour interval 160 m.; isotherm interval 6° C. Much of the analysis beyond the area covered by the other 10-mb. charts is an estimation, based largely upon extrapolated data.

passing close to the pole. The Astrajet was stretched into a great loop that crossed over the pole and thereby split the intense polar vortex and its pool of cold air into two much weaker cold vortices, one over Europe and the other over the Gulf of Alaska. At the pole, these events climaxed a temperature increase during January of more than 50° C. and a height increase of more than 3.5 km. (Such large changes also occurred in the Keflavik area in 1957 (Teweles [13]).) The largest portion of the cold air that had surrounded the pole was carried southward over the Greenland area to Europe. There, too, large rapid changes were taking place. On January 23 when a 10-mb. temperature of —21° C. and a 10-mb. wind of 148 kt. from 250° were reported at Bitburg, the 50-mb. temperature was —50° C. at this station in contrast to —82° C. at ship "A" (62° N., 33° W.). At 50 mb., deep Lows centered northeast of Iceland and in north-central Siberia were connected by a trough across the Arctic coastline of Eurasia. Subsequent retrogression of the former Low from the vicinity of Iceland to a point over southern Greenland was accompanied by the backing of winds at Keflavik to southwesterly and by warming to —13° C. at 25 mb. at 0600 GMT on January 30. With the appearance of a deep Low over northern Europe on February 1 (fig. 9) the Greenland Low filled rapidly. At Keflavik stratospheric winds shifted to northwesterly, and the temperature at this station plunged again as indicated in table 1. The second Keflavik warming came on February 10 with the arrival of warm air from eastern Siberia where it had persisted since the beginning of the month, passing over the pole on February 7 and 8 and thence southward across Greenland.

The "explosive warming" phenomenon in 1958 as in other years was part of a hemispheric change in circulation. The preferred location for the appearance of unusually high temperatures seems to be in a portion of the Astrajet moving from a southerly direction along the eastern side of an intensifying westward-moving (retrogressing) stratospheric trough or low center. The peak temperature at a station frequently occurs as the axis of the Astrajet sweeps to the left across the station in the direction of low pressure. Near the center of highest temperature the wind decreases, and 10-mb. height increases greatly at this stage. At the same time, anomalously low temperatures appear in the northerly current west of the Low.

On the other hand when systems move eastward, the warm air center makes its way around to the northerly current ahead of the advancing ridge line. The maximum

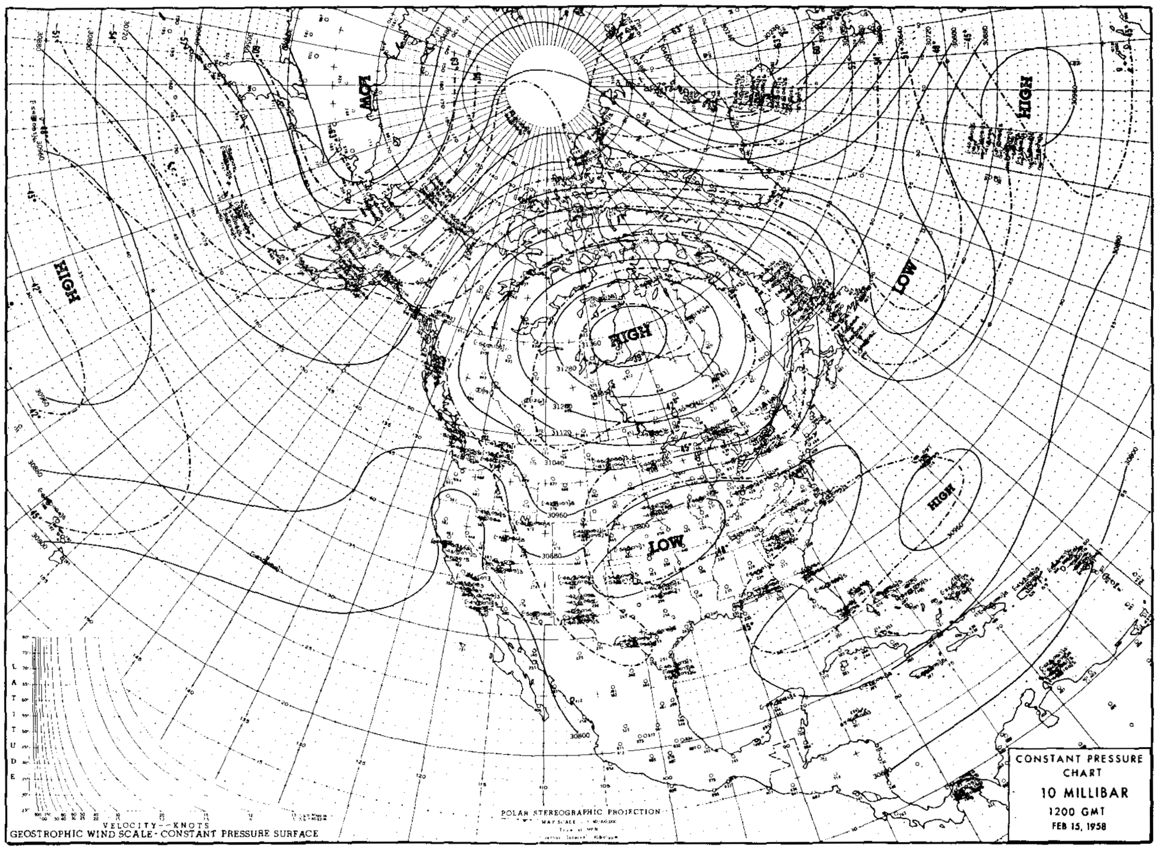

Figure 10.—The 10-mb. chart for 1200 GMT February 15, 1958, from [18]. Contours and isotherms as in figure 2.

temperatures reached seem to be less extreme than those observed with retrogressing systems. In either case, the rate of temperature change depends upon the rate at which the jet axis moves normal to itself.

8. REESTABLISHMENT OF CIRCUMPOLAR FLOW

(Mid-February to Mid-April 1958)

On February 15 (fig. 10), the temperatures and temperature gradients over the map area were about the same as those observed at the beginning of October. Only weak temperature advection was indicated. The strongest winds had decreased from 200 kt. to below 50 kt.

By late February, the weak circulation of a Low centered over Canada dominated the North American area. Hemispheric 50-mb. charts indicate that in eastern and western Eurasia there were two other low centers, both deeper and with more vigorous circulations than the one over North America.

Throughout March, weak ventilation of the polar stratosphere by mid-latitude air prevented radiative thermal equilibrium in the Arctic. By the time the cross-polar flow was halted with return of low pressure to the vicinity of the pole on April 5 (fig. 11), the sun had moved northward across the equator and temperatures rose generally over the middle and high latitudes. Although the flow in the higher latitudes of the Northern Hemisphere appeared essentially circumpolar, the 50-mb. charts show a marked eccentricity toward the Eurasian sector.

9. THE TRANSITION TO SUMMERTIME EASTERLIES

(Late April to Early June 1958)

In the second half of April 1958, the cellular structure of the contour pattern was becoming increasingly evident, and temperatures generally were rising rapidly. By May 5 (fig. 12) the circulation over North America had undergone a radical change toward meridional flow with cut off Highs and Lows. During the remainder of the month, the pressure at the pole rose rapidly and the low pressure cells in the middle latitudes faded into weak troughs. By the end of May easterly winds dominated the Arctic and the subtropics, and westerly components had almost entirely disappeared from mid-latitudes. In early June two separate bands of maximum easterlies were still apparent in the Arctic and in the subtropics, but before the arrival of the summer solstice they merged.

10. VARIATIONS IN THE TROPICAL CIRCULATION AT 10 MB.

Much of the literature on the subject of conditions at 10 mb. over the Tropics leaves the impression of an extremely steady current of easterly winds. However, some recent papers indicate the existence of substantial

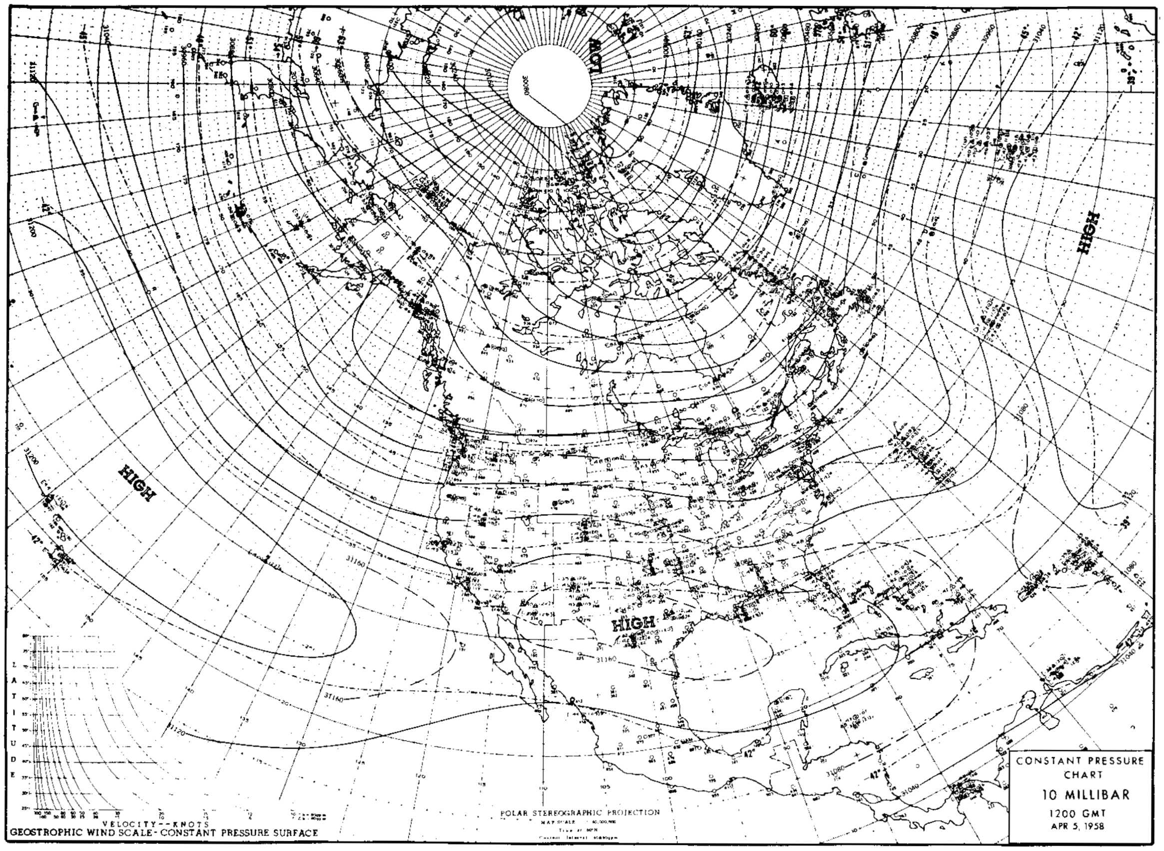

Figure 11.—The 10-mb. chart for 1200 GMT April 5, 1958, from [18]. Contours and isotherms as in figure 2.

year-to-year and day-to-day changes in the 10-mb. flow of the Tropics. That complete reversal of the equatorial flow may take place from one year to the next at Christmas Island (2° N., 157° W.) is shown by McCreary [5]. The majority of 10-mb. winds observed at this station in January and May of 1957 were westerly, but in the same months of 1958 they were easterly. McCreary comments on the "layered, predominantly zonal flow with great intra-seasonal steadiness and remarkable inter-annual variability." From some level above 10 mb., the layers of opposing zonal winds seem to descend slowly through the stratosphere, replacing each other with a complete cycle of about 26 months. This period is reminiscent of the famous Southern Oscillation (Berlage and DeBoer [1]) of 28 months period in the position of the sea level anticyclone of the subtropical South Pacific Ocean. Investigation of a possible relation between these periodic phenomena is recommended.

The danger of reliance upon "great intra-seasonal steadiness" is demonstrated by the rapid interdiurnal changes in the 10-mb. circulation observed over the Caribbean in late January 1960. Riehl and Higgs [7] describe a shear line that on January 28 moved northward out of South America and across the Caribbean at a speed of from 6 to 16 kt. With approach and passage of the shear line, reported easterly winds up to 100 kt. or more decreased rapidly and shifted to westerly. With the passage of a following ridge line a few days later, easterly winds again dominated the Caribbean.

Thus, 10-mb. wind forecasts based on persistence or on climatology, particularly an incomplete climatology, may occasionally be subject to great error. We conclude that even in the Tropics, operations critically dependent upon conditions at 10 mb. require the same careful forecast procedures, based on fresh, accurate data, that are used in forecasting at lower levels.

11. SUMMARY AND CONCLUSION

Although this description of the events of an entire year at an elevation of about 30 km. is necessarily incomplete, it serves to announce the availability of a recently published set of 10-mb. charts [18]. Much of the reasoning concerning cause and effect and the association of phenomena in the stratosphere is highly speculative but is included in the discussion as a basis for future speculation and investigation. It is very tempting to relate events in the stratosphere to tropospheric phenomena, such as westerly wind indices, cyclonic activity, and jet stream patterns on the one hand, or to solar disturbances and ionospheric phenomena such as sudden commencements, geomagnetic storms, and aurora on the other hand. However, the available history of stratospheric circulation is still so short that conclusions cannot be statistically validated. Even so, there are almost always enough

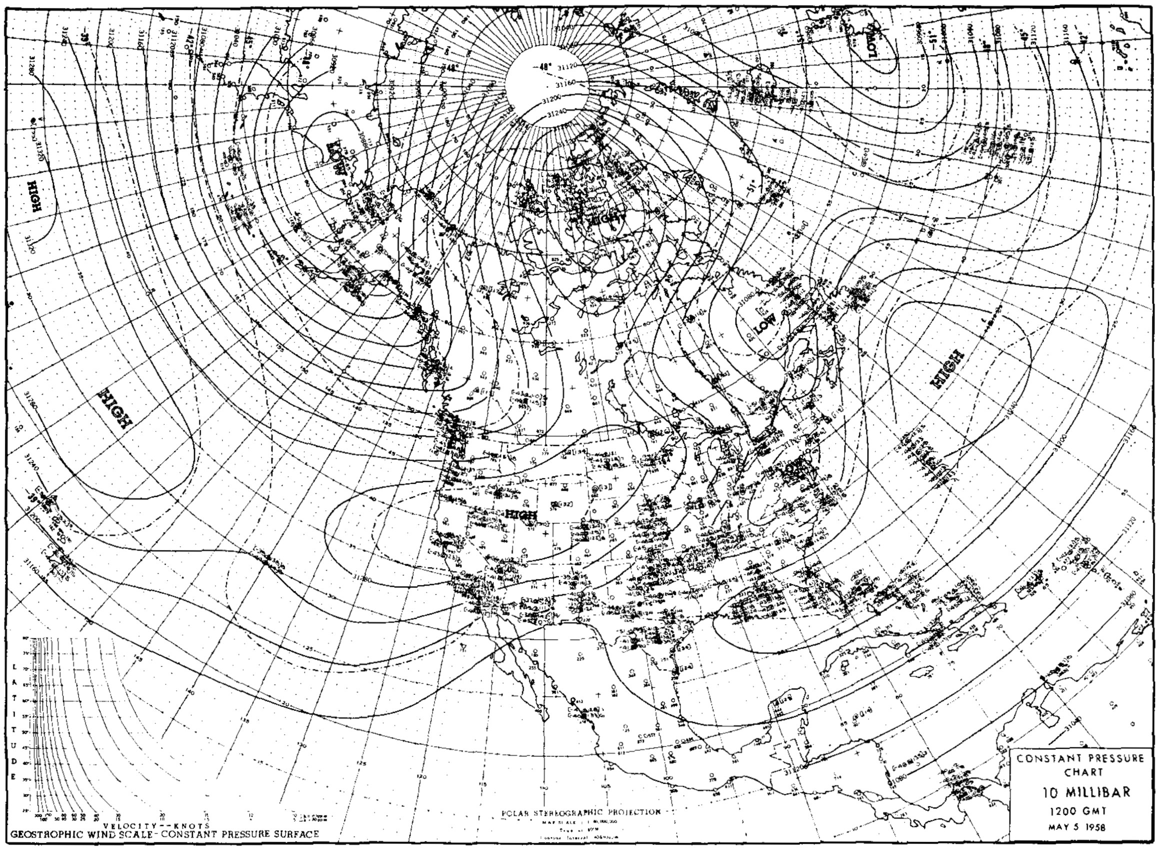

FIGURE 12.—The 10-mb. chart for 1200 GMT May 5, 1958, from [18]. Contours and isotherms as in figure 2.

analyses on record to provide a case history contradicting the theory suggested by the detailed analysis of another case history.

One stratospheric characteristic that leads to fallacious conclusions is the very slow development and movement of phenomena over a long period. Thus a very warm mass of air may appear in the stratosphere and pass over one station after the other during the course of 1 or 2 weeks. This gives ample time for any of a score of solar or terrestrial phenomena to occur and be designated as the cause or the effect of the stratospheric warming at one of the stations. A basis for many doubtful statistical conclusions is the fact that radiosonde observations rarely reach very high levels unless the radiosonde balloon is prevented from breaking by unusually high stratospheric temperatures. Thus, average values of actually observed 10-mb. data are biased toward those typical of abnormally warm situations.

Many of the problems that beset stratospheric research can be solved by more copious, more representative, and more accurate data. The balloon makers have improved the radiosonde vehicle in spectacular fashion with relatively little increase in cost. However, in many countries of the world, the radiosonde in use has scarcely any capability above the 25-mb. level. The most pressing requirement is for additional wind data through the more universal use of tracking equipment to follow the radiosonde through strong wind currents to the top of the soundings.

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New Weather Bureau Publications

Technical Paper No. 29, Part 5, "Rainfall Intensity-Frequency Regime—Great Lakes Region," Washington, D.C., 1960, 31 pp.; for sale by Superintendent of Documents, U.S. Government Printing Office, Washington, 25, D.C., Price $1.50.

Contains rainfall intensity-duration-area-frequency regime, with other storm characteristics, for durations of 20 minutes to 24 hours, area from point to 400 square miles, frequencies for return periods from 1 to 100 years, for the region between longitudes 80° and 90° W. and north of latitude 40° N.

Technical Paper No. 38, "Generalized Estimates of Probable Maximum Precipitation for the United States West of the 105th Meridian for Areas to 400 Square Miles and Durations to 24 Hours," Washington, D.C., 1960, 66 pp.; for sale by Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C., Price $1.00.

Provides generalized estimates of probable maximum precipitation for western United States for hydrologic design, and details what the values presented represent, how they were obtained, how they should be used, and how accurate they are.